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Validation Studies of the Numerical Tool PANSHIP for Predicting the Calm Water Resistance of the Armidale Class Patrol Boat

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ABSTRACT

DSTO has recently joined the International collaborative consortium FAST3.JIP with the aim to develop a numerical capability for the prediction and analysis of the resistance, seakeeping and seaway loads of high speed semi-planing hullforms. It has been reported previously that DSTO has undertaken a series of calm water resistance scaled model tests on the Armidale Class Patrol Boat (ACPB). In addition to this, DSTO has also undertaken a series of full-scale calm water resistance trials onboard an ACPB. Both the experimental data and full-scale powering trial data has been used to validate the numerical tool PANSHIP. It was important to ensure that the calm water behaviour across the range of speeds is predicted correctly as this ensures the correct pressure distribution under the hull is predicted and hence the ship motions are accurate. Once fully validated this tool can be utilised to increase the understanding of any potential fuel saving strategies for the ACPBs and the through-life structural management of the platform. This report presents the outcomes from this validation study showing the results of the PANSHIP predictions for experimentally obtained running trim, rise of centre of gravity and total resistance versus speed relationships and for running trim and total resistance versus speed relationships obtained from full-scale trials.

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Executive Summary

The Armidale Class Patrol Boats, (ACPBs), are a semi-planing hullform which has significant differences in the resistance, manoeuvring and seakeeping capabilities when compared to other RAN platforms. The Australian Defence Science and Technology Organisation, DSTO, has recently joined the International Collaboration, FAST3 Joint Industry Program, which is aimed at developing more advanced numerical tools to accurately predict the non-linear motions, resistance, manoeuvring and wave induced loads of these semi-planing hull forms.

As part of the development of these numerical tools an extensive validation study is required. DSTO has recently reported on the outcomes of the calm water resistance experimental study that was undertaken to obtain a database for these validation studies. This experimental program included studying the effect that speed, displacement and the angle of the stern flaps had on the resistance of the hull.

In addition to the model test program, DSTO has also undertaken a series of full-scale powering trials onboard the ACPBs. Data recorded during the trial included ship motions, engine power, torque and RPM (revolutions per minute) for a range of speeds. This full-scale sea trial data in combination with the model scale data form an extensive database that has been used to validate the calm water resistance predictions and running trim versus speed relationships of the ACPBs.

More recently DSTO has completed the numerical component of this validation study using the FAST3.JIP tool, PANSHIP, to model the calm water resistance, rise of centre of gravity, and running trim versus speed relationships for the ACPB at several different operational load conditions and trim tab angles. It was important to ensure that the calm water behaviour across the range of speeds is predicted correctly as this ensures the correct pressure distribution under the hull is predicted and hence the ship motions are accurate. This report presents the outcomes from this validation study showing the results of the PANSHIP predictions for experimentally obtained running trim, rise of centre of gravity and total resistance versus speed relationships and for running trim and total resistance versus speed relationships obtained from full-scale trials.

It is observed that for the various load conditions considered, PANSHIP predictions or the running trim were within 0.2 deg, the rise was within 0.1 m and the total resistance coefficient within 0.7 of the experimental values.

PANSHIP predictions of the total resistance of the ACPB were then compared to other existing numerical methodologies in the software suite Maxsurf [2]. These comparisons were undertaken for all the load conditions considered and with the trim tab set in the fully "retracted" position. The Maxsurf suite of tools were more accurate than PANSHIP but the Maxsurf numerical methodologies do not have the capability to model trim tabs. PANSHIP does have the capability to model the trim tab set to any angle. In other words, of the numerical tools used within this study, the influence of trim tab angles on the total resistance of the vessel can only be determined using PANSHIP.

The PANSHIP predictions of the running trim and total resistance of the ACPB were also compared with the data obtained from full-scale sea trials. This comparison showed that PANSHIP predicts the running trim of the Armidale Class Patrol Boats within 0.2 deg. This comparison also showed that PANSHIP predicts the resistance of the Armidale Class Patrol Boats within approximately 14 %, across its entire speed range where it operates in either displacement or a semi-planing mode. Traditional seakeeping, manoeuvring, resistance and operational load numerical prediction tools are based on the assumption that the hullform being considered is a displacement hullform.

The PANSHIP numerical modelling tool provides the Australian Department of Defence with a capability to enhance their understanding of the operational performance of these semi-planing platforms including fuel savings and life-of-type studies. Further work is currently being undertaken to fully validate the ship motion and seaway loading, including slamming, predictive capability of PANSHIP. An accurate understanding of the loading is important for the ACPBs through life management and the life-of-type structural fatigue studies. These tools are also applicable to support any future acquisition programs that may utilise semi-planing craft.

Authors

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Maritime Division

Terry Turner currently works in the Platform Analysis and Performance group of MD. He is currently involved in several research programs relating to seakeeping, resistance, manoeuvring and seaway loads of naval vessels. From May 2007 until May 2008 he was awarded a Defence Science Fellowship where he was attached to the Maritime Research Institute Netherlands. He is the Australian point of contact for several international research collaborations in the areas of ship motions, stability and seaway loads.

Frans van Walree
Maritime Research Institute Netherlands

Frans van Walree graduated from Delft University of Technology in Naval Architecture in 1985. Since graduating he has been employed at the Maritime Research Institute Netherlands. Since 2000 he has been a project manager in the seakeeping department of MARIN and is mainly involved in the dynamic stability of (naval) ships and the hydrodynamic performance of fast and/or advanced ships. From April 2012 until May 2013 Frans undertook a work placement at DSTO where he continued the development of the seakeeping code PANSHIP.

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Contents

Acronyms

ACPB	Armidale Class Patrol Boat
AMC	Australian Maritime College
A_F	Wind frontal area (m^2)
AP	Aft Perpendicular
B	Maximum submerged width of hull (m)
C_f	Hull surface coefficient
Cp	Prismatic coefficient
C_T	Total resistance coefficient
C_W	Wind resistance coefficient
DNPS	Directorate of Navy Platform Systems
DSTO	Defence Science and Technology Organisation
FP	Forward Perpendicular
Fn or Fr_L	Froude Number
Fn_v	Volume Froude Number
η_D	Propulsion efficiency
η_O	Propeller open water efficiency
η_H	Hull efficiency
η_R	Relative rotative efficiency
ITTC	International Towing Tank Conference
LCG	Longitudinal Centre of Gravity from midships (m)
LWL or L	Length Waterline (m)
MARIN	Maritime Research Institute Netherlands
MD	Maritime Division
MS	Mid Ships
N	Propeller/engine revolutions (1/min)
ρ	Density of water (kg/m^3)
ρ_w	Density of wind (kg/m^3)
Q	Propeller/engine torque (Nm)
R_f	Hull roughness
R_w	Wind resistance (N)
RPM	revolutions per minute
R_T	Total resistance (N)
R_T	Ship resistance (N)
S	Wetted surface area (m^2)
T_t	Draught of transom at calm water line (m)
U	Ship speed (m/s)
V	Displaced volume (m^3)
V	Speed (m/sec)
V_k	Speed (knots)
Pd	Developed power at propeller/engine (W)

1. Introduction

The Defence Science and Technology Organisation, DSTO, has been tasked to undertake several research programs in support of the Armidale Class Patrol Boats. One of these programs is to develop an understanding of the effects that biofouling of a hull has on the performance and fuel consumption of a Patrol Boat. An outcome of another research program is to understand the appropriate wave loading, including slamming loads, that the Patrol Boats experience throughout their life and the implications that this loading has on the structural fatigue life of the vessel. A key component of both these programs is the development and validation of numerical tools to support these studies.

The Maritime Division, MD, of DSTO are members of the international FAST3 Joint Industry Program, FAST3.JIP, whose aim is to develop knowledge and capability to better understand high speed ship hydromechanics. The two key components of work under the FAST3 consortium are focussed on; (1) the development of new calm water resistance and manoeuvring assessment methods and (2) the development of simulation tools for determining the wave loading, including slamming loads for displacement, semi-planing and planing vessels.

Traditional seakeeping, manoeuvring, resistance and operational load numerical prediction tools are based on the assumption that the hullform being considered is a displacement hullform. Maritime vessels can be defined into three categories based upon a speed/length ratio:

$$\text{Speed/length Ratio} = V_k / (\sqrt{LWL})$$

Where: V_k = speed (knots)
LWL = length waterline (m)

These categories are: (1) displacement, (2) semi-planing and (3) planing hullforms. A displacement hullform is one which the hull is predominantly supported by buoyancy and changes in draft and trim are small with increasing speed. These hullforms typically have a speed/length ratio up to 1.3. A semi-planing hullform is capable of developing a moderate amount of lift and start to trim down by the stern with increasing speed. The semi-planing hullforms typically have a speed/length ratio between 1.3 and 3.0. A planing hullform is configured to develop dynamic lift so that the draft decreases with speed and these typically have a speed/length ratio greater than 3.0 [3].

The ACPB operates across both the displacement and semi-planing hullform modes and even into the planing mode. When operating at slower speeds, i.e. less than 9.3 knots the ACPB is considered to be in displacement mode. At higher speeds, between approximately 9.3-21.6 knots, the ACPB is considered to be in semi-planing mode, see Table 2. As previously stated, the applicability of traditional seakeeping tools when analysing the ACPBs is limited to the slower speed range i.e. when the vessel is operating in displacement mode. For any understanding of the capability of these hullforms over the entire operational speed range, advanced semi-linear or non-linear numerical tools are required to be able to analyse the hullform in the semi-planing and planing modes. These tools, one of which is PANSHIP [4], are being developed within the FAST3 JIP collaboration.

When the ACPBs are operating in the semi-planing mode the trim of the vessels varies with speed therefore prior to any seakeeping analysis for the prediction of seaway and slamming loads, it is important that validation studies of the prediction of the running trim angles with speed is undertaken. Turner and McKillop [1] recently undertook a series of calm water resistance tests on a 1:25 scaled model of the ACPB and determined the calm water resistance, running trim and rise of centre of gravity relationships with speed. In addition to the model tests, a dedicated full-scale calm water resistance sea trial was undertaken on an ACPB. Data from this trial included the engine power, torque and RPM measurements being recorded for a variety of speeds. The data from the model tests and full-scale trials has been used to validate the numerical tool PANSHIP.

This report will provide an overview of the results from the validation studies of PANSHIP for the predictions of the calm water resistance, running trim and rise of centre of gravity versus speed relationships of the ACPBs for various load conditions. Once fully validated for these relationships, further work can then be undertaken to validate PANSHIPs predictions of seaway loads including slamming. These additional validation studies will be the subject of subsequent reports.

The knowledge gained and the capabilities developed in both the research programs described will greatly enhance the understanding of the operational performance of the ACPBs and any life-of-type extension studies. Outcomes will also provide guidance to the Royal Australian Navy for any potential cost saving strategies for fuel consumption. These capabilities and the increased knowledge in these areas will also be valuable when considering any potential candidates for future acquisition programs that may utilise a semi-planing craft.

2. Experimental

2.1 Overview

A 1:25 scale model of the ACPB was constructed and a series of calm water resistance tests were undertaken in the Towing Tank at The Australian Maritime College, University of Tasmania. The objective of this model test program was to generate a calm water resistance and running trim versus speed relationships for the ACPB at several different operational load conditions and a range of trim tab angles.

Table 1 outlines the relevant hydrostatics for the load conditions tested in the calm water resistance testing program. Both the model scale, (model), and full scale, (ship), values are shown. The model scale hydrostatics was calculated for fresh water whereas the full-scale hydrostatic values are for salt water. All values are for the bare hull, i.e. no appendages.

Table 1 ACPB Hydrostatics for Load Conditions tested

Load Condition	Displacement		Trim (by the stern)		LWL		Wetted Area (S)	
	model (kg)	ship (t)	model (m)	ship (m)	model (m)	ship (m)	model (m^2)	ship (m^2)
1	18.732	300.5	0.000	0.000	2.085	52.13	0.590	368.9
2	18.732	300.5	0.012	0.300	2.078	51.95	0.584	365.1
3	18.732	300.5	0.024	0.600	2.071	51.77	0.579	361.9
4	21.229	340.6	0.000	0.000	2.090	52.25	0.625	390.9

As the model was designed for both calm water resistance and seakeeping tests the model was designed such that several of the appendages could be removed for the calm water resistance tests. The removable appendages included a pair of bilge keels, roll stabiliser fins, the skeg and a set of rudders. The model also included a pair of adjustable trim tabs at the stern. The hullform and associated appendages were all scaled and manufactured according to the AUSTAL Ships drawings for the 56.8 m Armidale Class Patrol Boat [5-11]. Figure 1 shows a photograph of the appended hull.

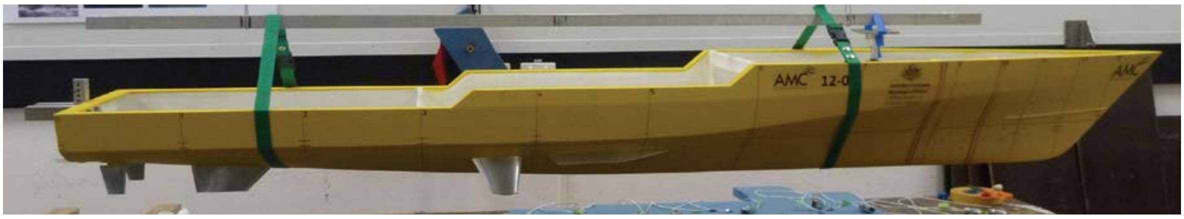

Figure 1 Photograph of 1:25 Scale model of Armidale Class Patrol Boat

The model setup, experimental test program and results are described in a previous publication [1]. In summary a total of 145 individual test runs were undertaken over a range of speeds, displacements, static trims and trim tab settings. The full-scale speeds and respective Froude numbers for the test runs are listed in Table 2.

Table 2 Speeds at which the model was tested

. Full-scale Speed (1:1) (knots)	Model Speed (m/s)	Froude Number (Fn)	Displacement Mode
5	0.51	0.11	displacement
7.5	0.77	0.17	
10	1.03	0.23	semi-planing
12.5	1.29	0.28	
15	1.54	0.34	
17.5	1.80	0.40	
20	2.06	0.45	
22.5	2.31	0.51	planing
25	2.57	0.57	
27.5	2.83	0.62	
30	3.09	0.68	

The trim tab angle definitions used in the experimental program were based on the neutral position as shown on AUSTAL Aft Trim Tab Detail Drawing [10]. The neutral position is defined as the position where the outboard underside corner of the flap is level with the lower edge of the transom at the trim tab recess; see "View on Frame 46 Looking Fwd" on AUSTAL Aft Trim Tab Detail Drawing [10]. The angle of 6.4 degree was used due to the limits that the trim tab on the scaled model could be set at. These angles are accurate to ± 0.1 degree.

Figures 2 -4 show photographs of the three different trim tab settings.

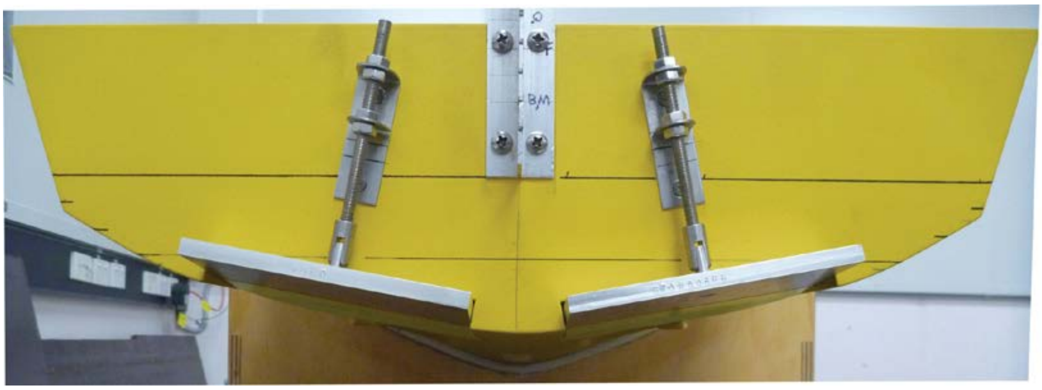

Figure 2 Photograph of Trim Tab in retracted position

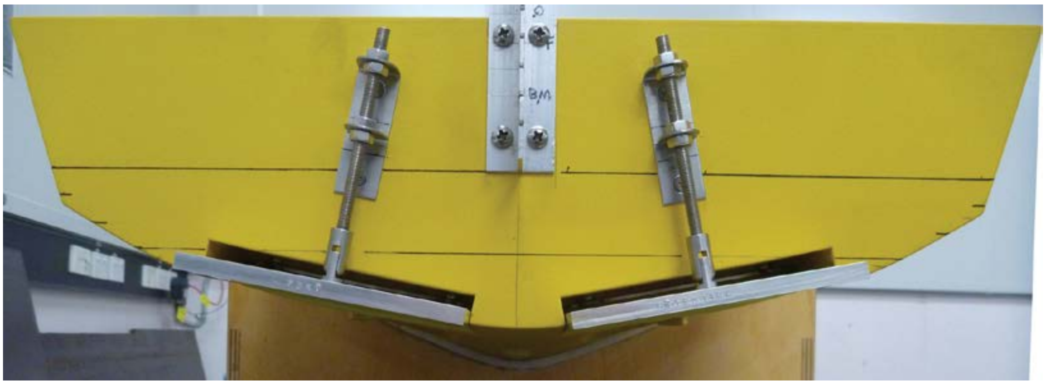

Figure 3 Photograph of Trim Tab in neutral position

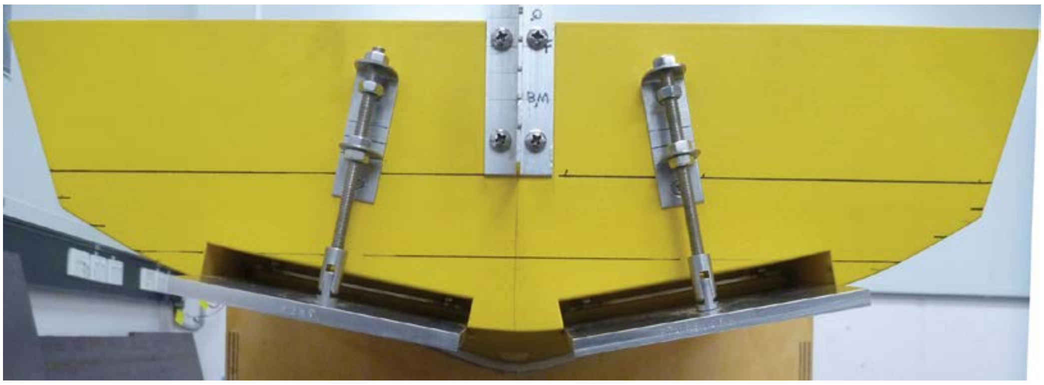

Figure 4 Photograph of Trim Tab extended position

2.2 Experimental Data Processing

2.2.1 ITTC 1978 Method.

The calculation of the total resistance coefficient was achieved by using the procedure as outlined in the ITTC recommended procedures [12].

The total resistance coefficient was calculated using:

$$C_T = \frac{R_T}{0.5\rho S V^2}$$

Where:
C_T = total resistance coefficient
R_T = total resistance (N)
ρ = density of water (kg/m^3)
S = wetted surface area (m^2)
V = speed (m/s)

2.2.2 Wetted Surface Areas

Wetted surface areas for the static condition were adopted in the experimental resistance calculations. Wetted surface area is used in the calculation of the total resistance coefficient for the model at ship scale. Although the wetted surface area varies with speed the accepted ITTC procedure for determining the resistance uses static wetted surface area.

2.2.3 Form Factor

The form factor is a factor that is commonly applied to the frictional resistance of a model to account for the 3 dimensional effects of viscous resistance. A typical value of the form factor for semi planing vessels is 0.1 [13] . PANSHIP accounts for the form factor therefore to enable a direct comparison with the experimental results they were multiplied by the same form factor of 0.1.

2.2.4 Froude Number

The Froude number defines the speed at which geometrically similar models and ship will develop wave systems which are geometrically similar.

3. Full-Scale Ship Trial

DSTO have recently undertaken a dedicated full-scale powering trial onboard an Armidale Class Patrol Boat. The boat was fitted with an extensive sensor network including strain gauges, accelerometers, motion sensor unit and torsion meters. The trials were undertaken in accordance to the ITTC Recommended Procedures for full-scale speed and power trials [14]. The trials were conducted over a range of speeds with the trim tabs in the fully retracted position. Power, shaft RPM and torque data were recorded from the torsionmeters and then the total resistance of the vessel calculated for the speeds tested.

At the time of writing this report good quality full-scale data and rise of the ACPB centre of gravity was not available.

3.1 Full-Scale Ship Trial Data Processing

The calculation of the Full-Scale Ship trial total resistance was achieved by using the procedure outlined below:

The following data was recorded during the dedicated sea trial:

N = propeller/engine revolutions (1/min)
Q = propeller/engine torque (Nm)
U = ship speed (m/s)

The total resistance was then calculated using:

$$R_T = 2\pi(N/60)Q\eta_D/U$$

and

$$\eta_D = \eta_O\eta_H\eta_R$$

Where R_T = ship resistance (N)
η_D = Propulsion efficiency (-)
η_O = Propeller open water efficiency (-)
η_H = Hull efficiency (i.e (1-t)/(1-w) where t = thrust deduction and w = wake fraction)
η_R = relative rotative efficiency

There was no efficiency data available for the ACPBs therefore values were obtained from propulsion tests on a very similar hullform and propulsion arrangement provided by the propulsion module of the MARIN Design-Ship Powering tool [15]. The propulsion efficiency, η_D, used in these calculations was 0.59. The method in the DESP tool was developed by Holtrop and Mennen which is based on statistical analysis of numerous model tests and full-scale trials [13].

4. Numerical Analysis

4.1 PANGEO

PANGEO 2.3 [16] is a software program that adapts the panel meshes of hulls and works automatically together with PANSHIP to iteratively obtain the ships forward speed equilibrium position, i.e. trim and sinkage, at a user specified range of speeds. PANGEO is required to be run in conjunction with the semi-linear version of PANSHIP.

4.2 PANSHIP

PANSHIP is a time domain panel method seakeeping code which has the capability of modelling the resistance, manoeuvring, seakeeping and wave loading, including slamming, of high speed craft. Both a semi-linear and a non-linear version of PANSHIP has been developed [4]. The semi-linear version assumes non-linear wave excitation and restoring forces but radiation and diffraction forces are based on the mean wetted surface of the hull. The non-linear version calculates the instantaneous wetted surface at every time step along with all the forces. The analysis in this paper was undertaken using the semi-linear version, PANSHIP 2.3. A time step of 0.1 seconds was required for all speeds considered in this study. At the lower speed ranges the use of a larger time step results in unstable green functions.

4.2.1 PANSHIP Data Processing

4.2.1.1 Experimental Test Program

The reference position for the trim tab angle definitions within the numerical tool PANSHIP is a different reference system to that used in the experimental program. PANSHIP defines the zero angle of the flap as being the continuation of the plane of the keel line at the transom (i.e. the buttock slope at the transom.)

The equivalent angles of the trim tab settings for both the experimental program and numerical analysis are outlined in Table 3.

Table 3 Equivalent Trim Tab angle definitions

Trim Tab Angle Definition		
Nomenclature used in this Report	**Experimental Program Definition**	**Numerical Analysis Definition**
retracted	retracted by 6.4 degree from the "AUSTAL" neutral position	retracted by 5.7 degree from the "PANSHIP" neutral position
neutral	0 degree from the "AUSTAL" neutral position	retracted by 1.1 degree from the "PANSHIP" neutral position
extended	extended by 6.4 degree from the "AUSTAL" neutral position	extended by 7.0 degree from the "PANSHIP" neutral position

The calculation of the total resistance coefficient was achieved by using the procedure as outlined in the ITTC recommended procedures [14].

The total resistance coefficient was calculated using:

$$C_T = \frac{R_T}{0.5\rho S V^2}$$

Where: C_T = total resistance coefficient
R_T = total resistance (N)
ρ = density of water (kg/m^3)
S = wetted surface area (m^2)
V = speed (m/s)

The values of R_T and S were obtained from the PANSHIP output file. Note that both the values of S for the numerical and experimental calculations were based on the wetted area for the vessel at zero forward speed. The value of R_T is the mean force, (Fx), in the X direction (longitudinal).

4.2.1.2 *Full-Scale Sea Trial*

The PANSHIP numerical simulations of the full-scale powering trials included the following appendages: skeg, fins, rudders, propeller shafts and bilge keels. The existence of all these appendages on the hull contributes to the overall total resistance of the vessel. PANSHIP is not able to numerically model the effect that bow thruster tunnels and the propeller shaft supports have on the resistance of the vessel therefore correction factors are also included to account for the bow thruster tunnel resistance (2.5%) and propeller shaft support (2%) frictional losses. These correction factors were obtained using the MARIN DESP program.

The total resistance of the vessel as determined from the full-scale trials will also include the effects of wind and hull roughness. In the numerical calculations, these are accounted for by adding their contribution to the total resistance determined by PANSHIP.

The wind resistance was obtained by the following:

$$R_w = 0.5\rho_w V^2 A_F C_W$$

Where: R_w = wind resistance (N)
ρ_w = density of wind (kg/m^3)
V = speed (m/s)
A_F = wind frontal area (m^2)
C_W = wind resistance coefficient

And the additional hull frictional resistance due to hull roughness is obtained by:

$$R_f = 0.5\rho V^2 S C_f$$

Where: R_f = hull roughness
ρ = density of water (kg/m^3)
S = wetted surface area (m^2)
V = speed (m/s)
C_f = hull surface coefficient

4.3 Other Resistance Predictive Methodologies

4.3.1 Maxsurf: Resistance

The Maxsurf Resistance numerical code [17] provides the prediction of the resistance for a variety of different hullforms. The two resistance prediction methodologies that are applicable to the ACPB type hull form are (1) Savitsky (pre planing) and (2) Holtrop. Both these methodologies are empirically based.

The Savitsky (pre planing) method is applicable for estimating the resistance of a planing hull before it gets onto the plane whereas the Holtrop method is applicable to displacement vessels including frigates etc. The ACPB operates in both a displacement mode, semi-planing and planing modes depending on the vessels speed see Table 2

The resistance methodologies are not only hull type dependent but also are only applicable within a certain speed and vessel dimension range. Table 4 shows the applicable range for both Savitsky (pre planing) and Holtrop methodologies along with the relevant ACPB values for the Load Conditions analysed.

Table 4 Range of Applicability for the Savitsky pre planing and Holtrop Resistance Methodologies [17]

Methodology	Parameter	Low	High	ACPB 300.5 t 0.0m static trim	ACPB 300.5 t 0.3m static trim	ACPB 300.5 t 0.6m static trim	ACPB 340.6 t 0.0m static trim
Savitsky (pre planing)	Fr_v	1.0	2.0	1.04-2.09 (> 15 knts)	1.04-2.09 (> 15 knts)	1.04-2.09 (> 15 knts)	1.03-2.06 (> 15 knts)
	$L/V^{1/3}$	3.1	12.4	9.5	9.5	9.4	9.2
	L/B	2.5	18.3	6.9	6.5	6.2	6.5
	B/T	1.7	9.8	3.5	3.5	3.5	3.5
	Fr_L	0.0	0.8	0 – 0.68	0 – 0.68	0 – 0.68	0-0.68
	Cp	0.55	0.85	0.61	0.68	0.71	0.69
Holtrop	L/B	3.9	15	6.9	6.5	6.2	6.5
	B/T	2.1	4.0	3.5	3.5	3.5	3.5

It should be noted that the ACPB calm water resistance model tests used for the validation of PANSHIP did not include appendages so the numerical predictions of these tests using Maxsurf were also based on a bare hull. The wind resistance for these simulations was assumed to be equal to zero. The numerical predictions of the full-scale resistance sea trials did include the contributions of all appendages and the effect of wind on the overall resistance of the vessel.

5. Results and Discussion

5.1 Numerical Analysis of Experimental Results

The ACPB model was tested over a range of speeds, displacements, static trims and trim tab settings. The effect that these variables had on the total resistance coefficient, running trim (static and dynamic trim), and rise of centre of gravity was determined. PANSHIP numerical predictions were undertaken and compared with the experimental results. The plots showing these comparisons are shown and discussed in the following sections. All dimensional values (eg speed, trim etc) discussed in the following sections relate to full-scale values.

5.1.1 300.5 t displacement, 0.0 m static trim

Figures 5 - 7 show a comparison between the experimentally determined running trim angles and the numerically predicted running trim angles for the 300.5 t displacement, 0.0 m static trim condition. In all cases considered PANSHIP predicted the running trim angles within 0.2 deg of the experimental values throughout both the low and high speed range. For speeds between Fn = 0.3 - 0.5, the difference between the numerical predictions and experiments were up to 0.3 deg. It is through this speed range that the ACPB is transitioning from displacement mode to planing mode. PANSHIP over predicts the running trim when the vessel is operating in displacement and semi-planing mode but under predicts the running trim across the planing mode speed range.

The method for trim tab forces used in this analysis using PANSHIP is based on model test data. An alternative approach would be to include the trim tabs as part of the panelled hull geometry. There is currently a research task within the FAST3.JIP to determine the best approach to model the effects of trim tabs.

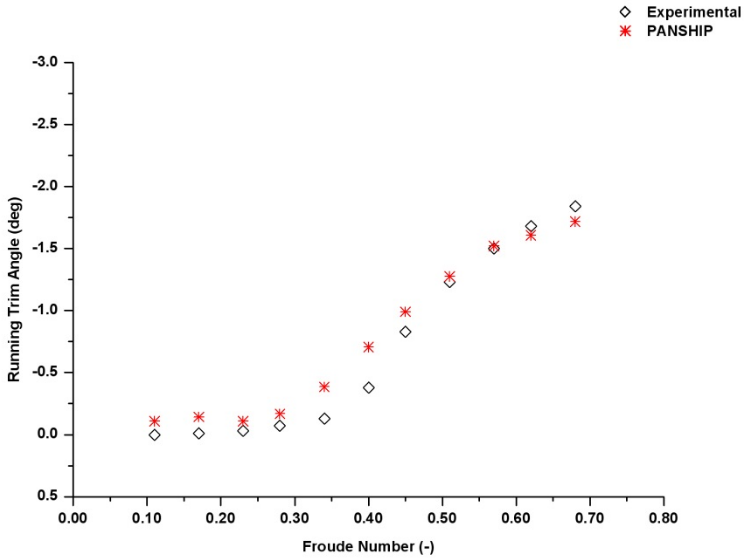

Figure 5 Experimentally determined and Numerically predicted Running Trim vs Froude Number (300.5 t displacement, 0.0 m static trim, trim tab in fully "retracted" position)

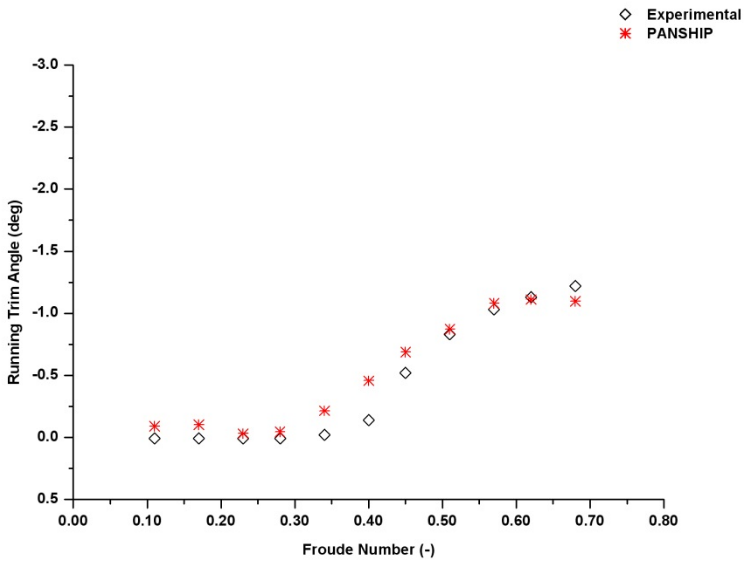

Figure 6 Experimentally determined and Numerically predicted Running Trim vs Froude Number (300.5 t displacement, 0.0 m static trim, trim tab in "neutral" position)

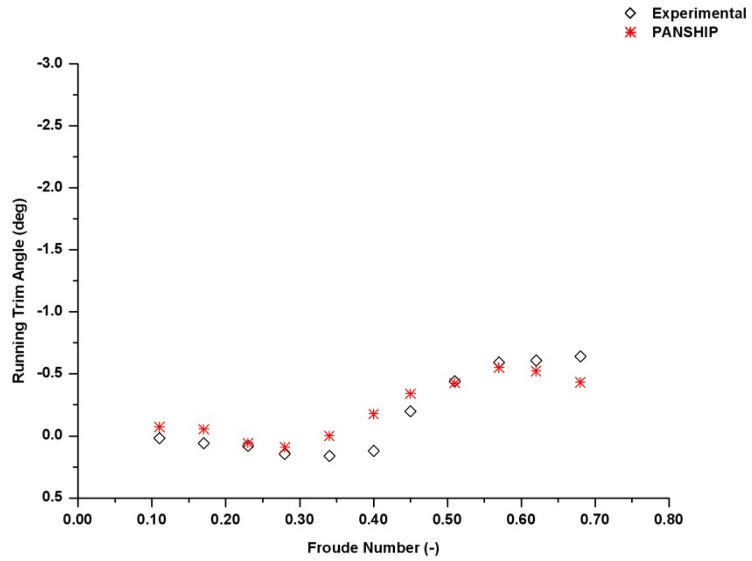

Figure 7 Experimentally determined and Numerically predicted Running Trim vs Froude Number (300.5 t displacement, 0.0 m static trim, trim tab in "extended" position)

Figures 8 - 10 show the comparison between the numerically predicted rise of the centre of gravity with the experimentally determined value. The overall trend of the rise vs speed is similar for both the numerical and experimental results in that as the vessel increases in speed, the centre of gravity initially sinks and then after approximately Fn equal to between 0.4 and 0.5 the centre of gravity rises again. The maximum difference observed between the numerical and experimental values of the rise is approximately 0.1 m (full scale). This difference is approximately 5% of the overall draught. The prediction of the rise of the vessel is known to be sensitive to the way the ship generated wave is determined using panel methods such as PANSHIP. This accuracy of the prediction of these waves is part of the ongoing research within the FAST3.JIP.

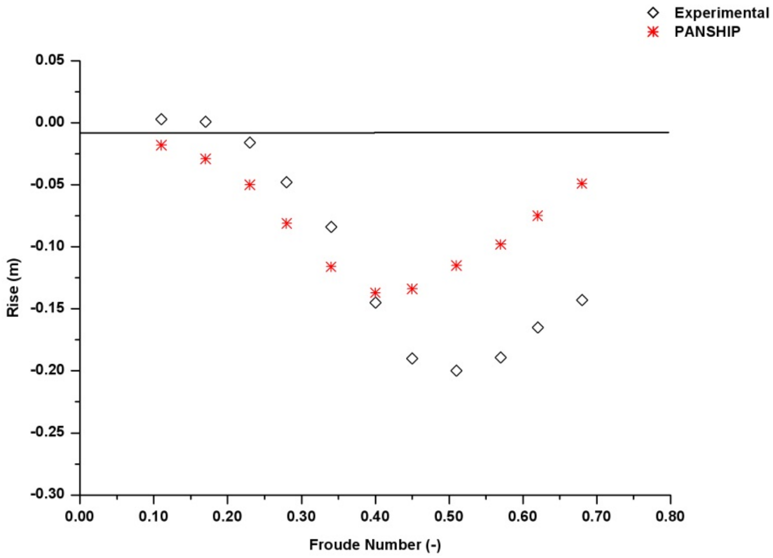

Figure 8 Experimentally determined and Numerically predicted Rise vs Froude Number (300.5 t displacement, 0.0 m static trim, trim tab in fully "retracted" position)

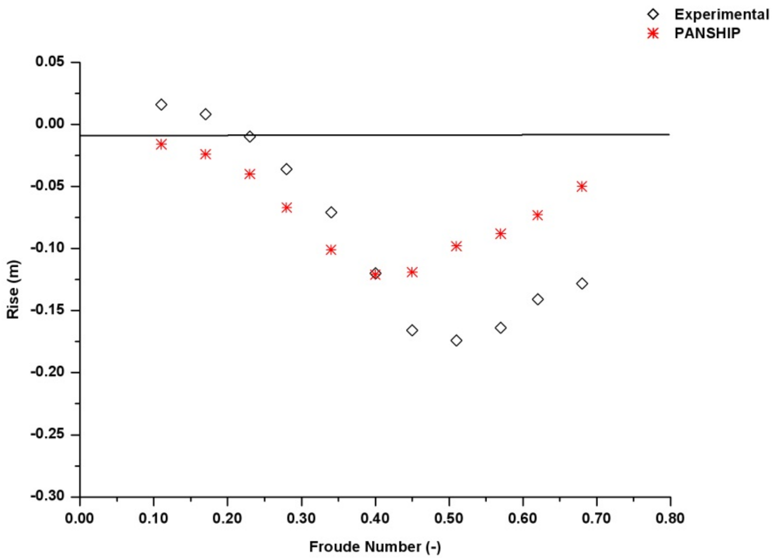

Figure 9 Experimentally determined and Numerically predicted Rise vs Froude Number (300.5 t displacement, 0.0 m static trim, trim tab in "neutral" position)

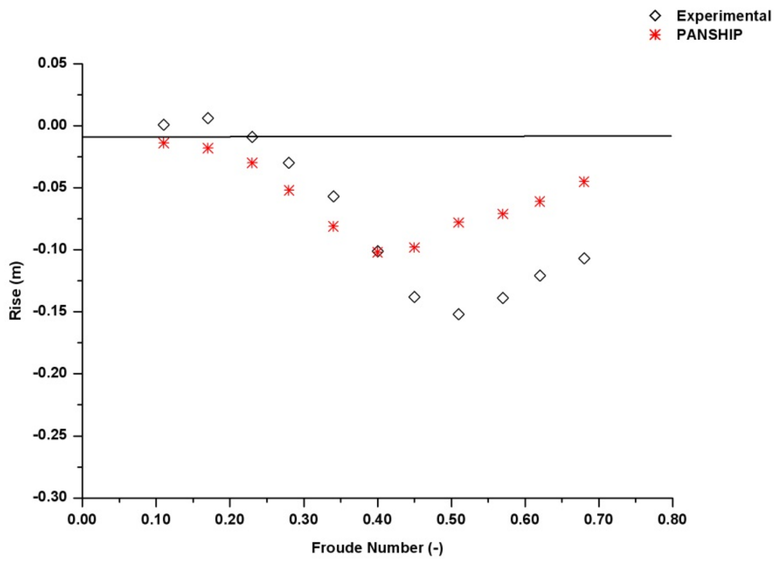

Figure 10 Experimentally determined and Numerically predicted Rise vs Froude Number (300.5 t displacement, 0.0 m static trim, trim tab in fully "extended" position)

Figures 11 - 13 show that at the speeds which the ACPB operates in semi-planing mode, (Fn > 0.28), the comparison between the experimentally determined and numerically predicted total resistance coefficient (x 1000) varies by up to approximately 0.7 depending upon the speed and angle of trim tab considered. Throughout this speed range the transom of the vessel is considered to be "dry" as it is fully ventilated hence has no hydrostatic force acting on it.

Across this slower speed range the transom of the ACPB is wet and hence a hydrostatic force acts on the transom resulting in a change of the resistance of the vessel. At low speeds there exists a dead-water region behind the transom and this is difficult to calculate accurately with panel methods such as PANSHIP.

Figures 11 - 13 also show that as the extension angle of the trim tab increases PANSHIP predicts the Total Resistance Coefficient with greater accuracy. As stated previously, the method for trim tab forces used in the PANSHIP analysis is based on model test data. An alternative approach would be to include the trim tabs as part of the panelled hull geometry. There is currently a research task within the FAST3.JIP to determine the best approach to model the effects of trim tabs.

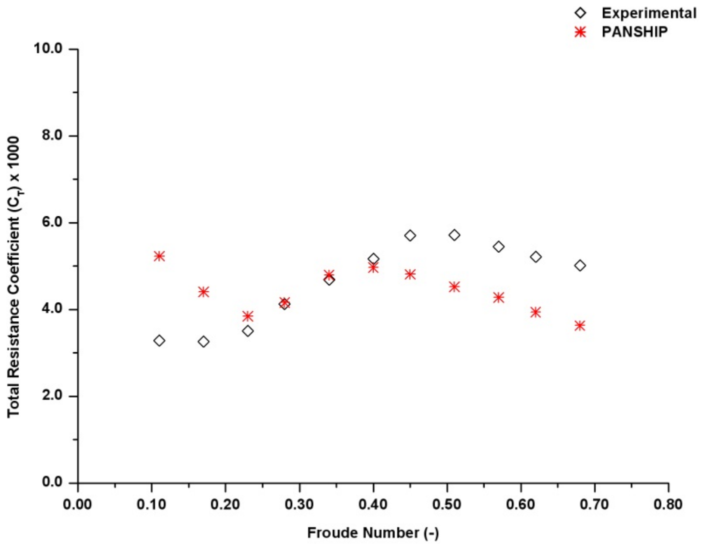

Figure 11 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (300.5 t displacement, 0.0 m static trim, trim tab in fully "retracted" position)

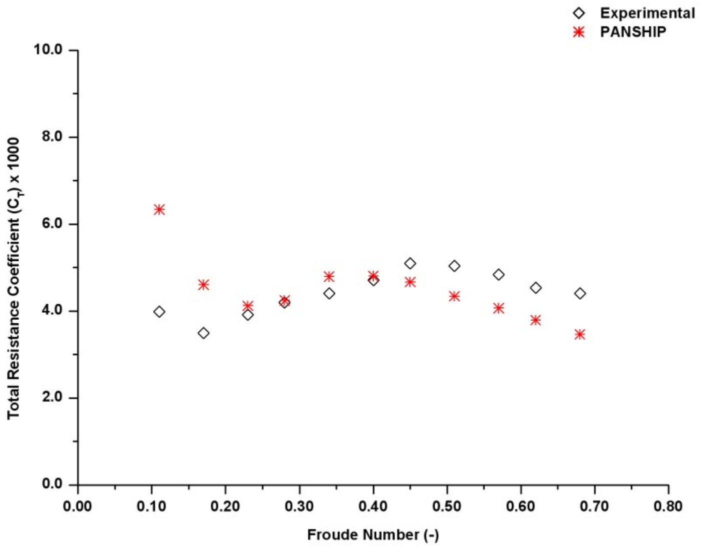

Figure 12 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (300.5 t displacement, 0.0 m static trim, trim tab in "neutral" position)

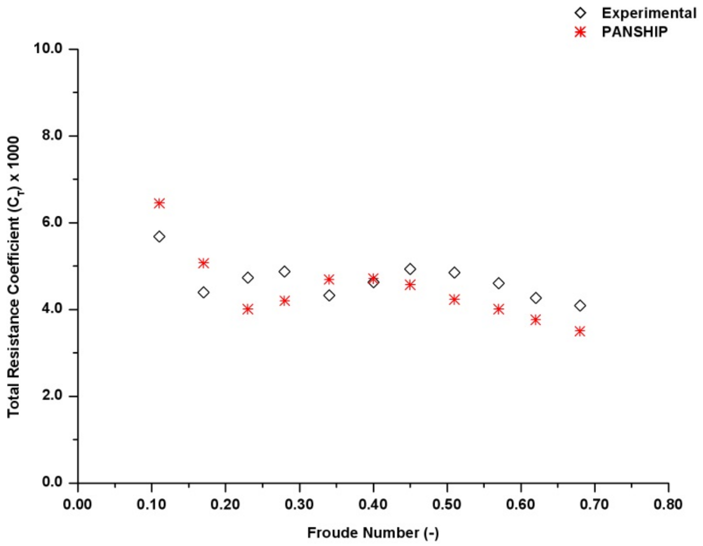

Figure 13 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (300.5 t displacement, 0.0 m static trim, trim tab in fully "extended" position)

Figure 14 shows three predictions using different numerical methods for the total resistance of the ACPB 300.5 t displacement 0.0 m static trim condition compared to the experimentally calculated total resistance. These results are for the fully retracted trim tab condition as the Holtrop and Savitsky pre planing methods in the Maxsurf Resistance program [17] do not have the capability to model trim tabs. It is therefore assumed that when the trim tab is in the "retracted" position they will have negligible influence on the overall total resistance of the vessel. It is observed that PANSHIP under predicts the total resistance at the higher speed ranges by up to 38%. This is consistent with the results that PANSHIP also slightly under predicts the rise of the vessel at these higher speeds. These differences may also be attributed to slight differences between the numerical and the experimental model. Another possibility for this difference could be attributed to PANSHIP neglecting the effect that spray drag has on the resistance and also the method by which PANSHIP approximate the ship generated wave. Both of these influences are subject to further investigation within the FAST3.JIP.

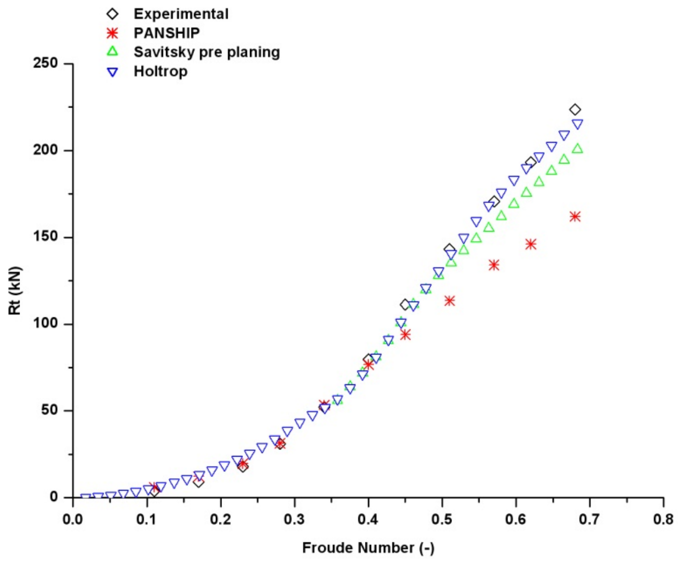

Figure 14 Experimentally determined and Numerically predicted Total Resistance vs Froude Number (300.5 t displacement, 0.0 m static trim, trim tab in fully "retracted" position)

5.1.2 300.5 t displacement, 0.3 m static trim by the stern

Figures 15 - 17 show a comparison between the experimentally determined running trim angles and the numerically predicted running trim angles for the 300.5 t displacement, 0.3 m static trim condition. PANSHIP predictions were only undertaken for the speeds at which the experiments were conducted. Similar to the 0.0 m static trim cases described above, the PANSHIP predictions for the running trim of the vessel were within 0.2 – 0.3 deg of the values obtained experimentally. The cases for the "retracted" and "neutral" trim tabs position show an increase in the trim by the stern as the speed increases. This trend is also observed for the slower speeds for the "extended" trim tab case but once again the numerical predictions show an unexpected decrease in the trim by the stern angle at the higher speeds. This decrease in trim angle maybe attributed to the existing methodology in PANSHIP to model the effect of trim tab on the motion of the vessel may not be the best approach. Alternative methods are currently being investigated as part of the FAST3.JIP research program.

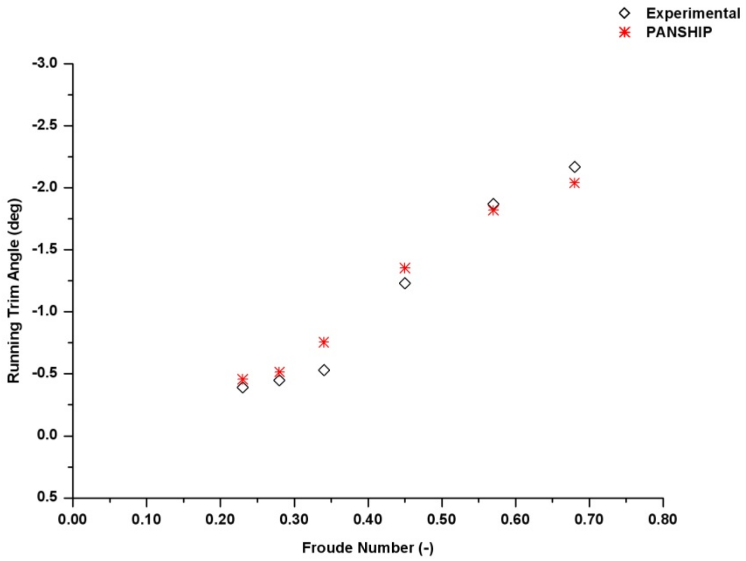

Figure 15 Experimentally determined and Numerically predicted Running Trim vs Froude Number (300.5 t displacement, 0.3 m static trim, trim tab in fully "retracted" position)

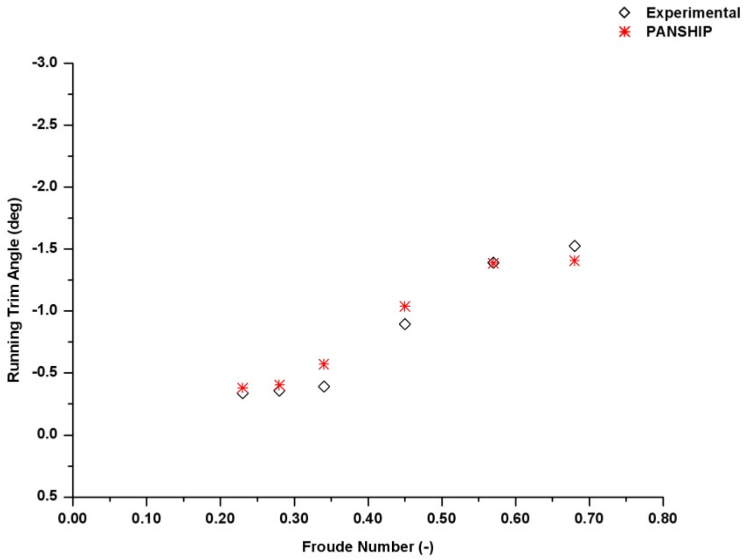

Figure 16 Experimentally determined and Numerically predicted Running Trim vs Froude Number (300.5 t displacement, 0.3 m static trim, trim tab in "neutral" position)

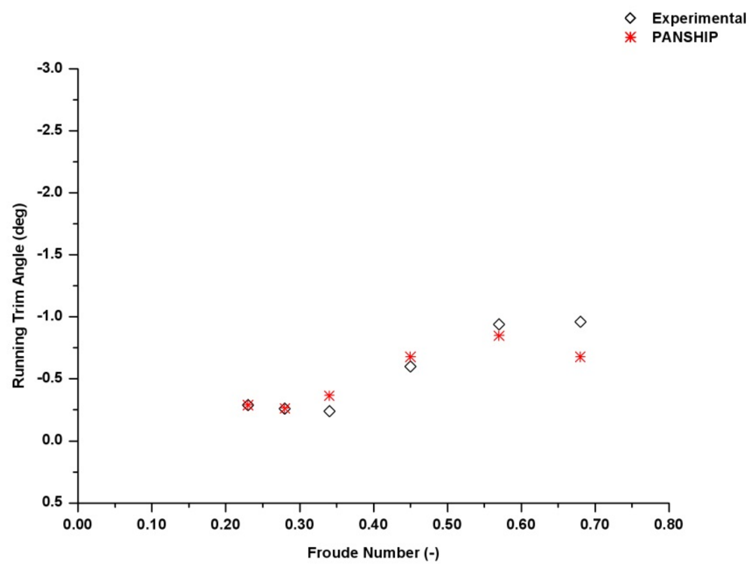

Figure 17 Experimentally determined and Numerically predicted Running Trim vs Froude Number (300.5 t displacement, 0.3 m static trim, trim tab in fully "extended" position)

The comparisons between the numerically predicted rise of centre of gravity and the experimentally determined values for the 0.3 m static trim case, as shown in Figures 18 - 20, are very similar to that observed for the 0.0 m static trim. (i.e. as the speed of the vessel increases the vessel initially sinks and then for speeds great than approximately Fn equal to 0.4 the vessel rises again). The differences observed between the experimentally determined and the numerically predicted values for rise range between 0.01 – 0.14 m. As previously stated, the prediction of the rise of the vessel is known to be sensitive to the way the ship generated wave is determined using panel methods such as PANSHIP. This accuracy of the prediction of these waves is part of the ongoing research within the FAST3.JIP.

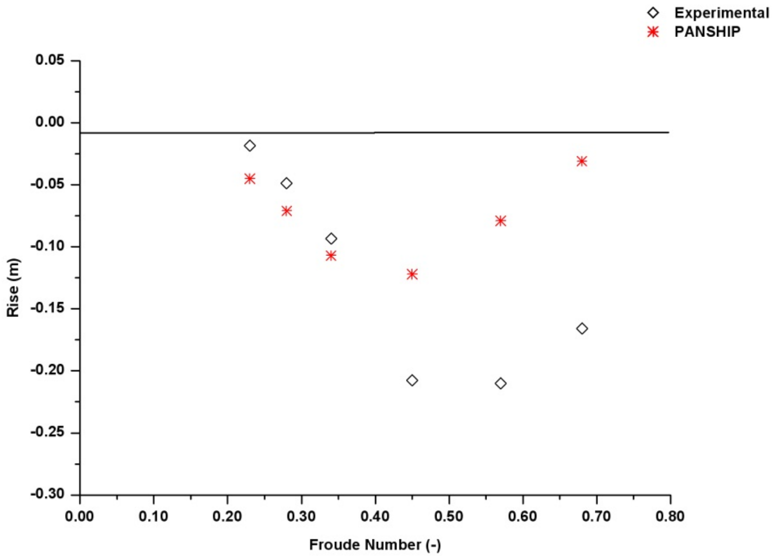

Figure 18 Experimentally determined and Numerically predicted Rise vs Froude Number (300.5 t displacement, 0.3 m static trim, trim tab in fully "retracted" position)

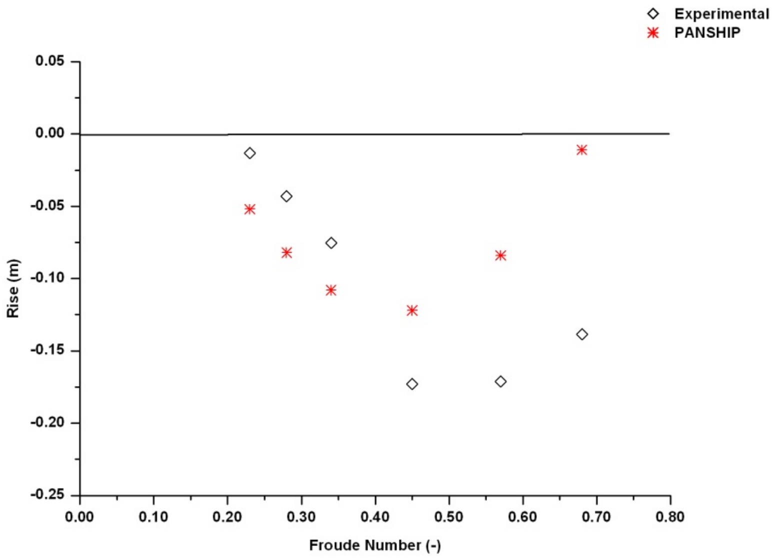

Figure 19 Experimentally determined and Numerically predicted Rise vs Froude Number (300.5 t displacement, 0.3 m static trim, trim tab in "neutral" position)

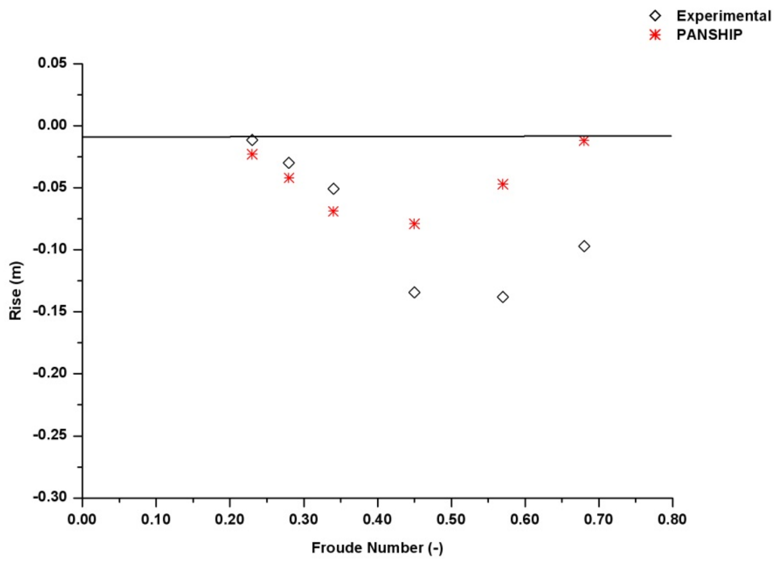

Figure 20 Experimentally determined and Numerically predicted Rise vs Froude Number (300.5 t displacement, 0.3 m static trim, trim tab in fully "extended" position)

As previously observed for the 0.0 m static trim cases as the extension of the trim tab increased, the accuracy of the PANSHIP predictions of the total resistance coefficient improved. The prediction of the resistance coefficient was more accurate at Fn < 0.34 compared to those at the higher speed ranges.

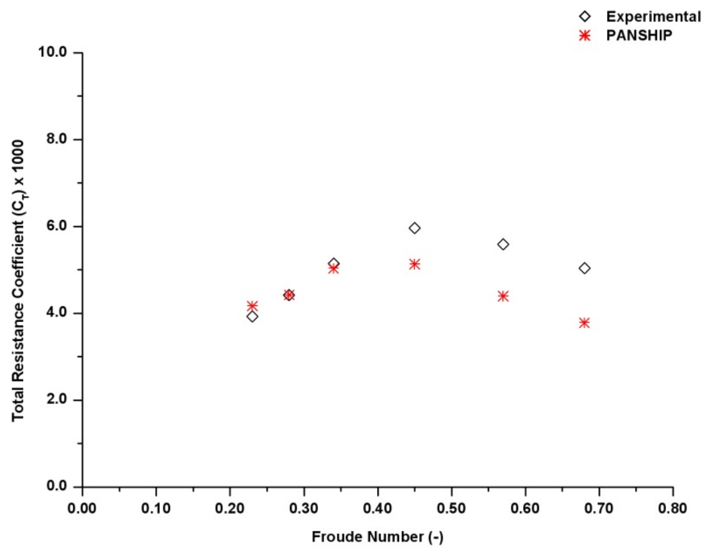

Figure 21 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (300.5 t displacement, 0.3 m static trim, trim tab in fully "retracted" position)

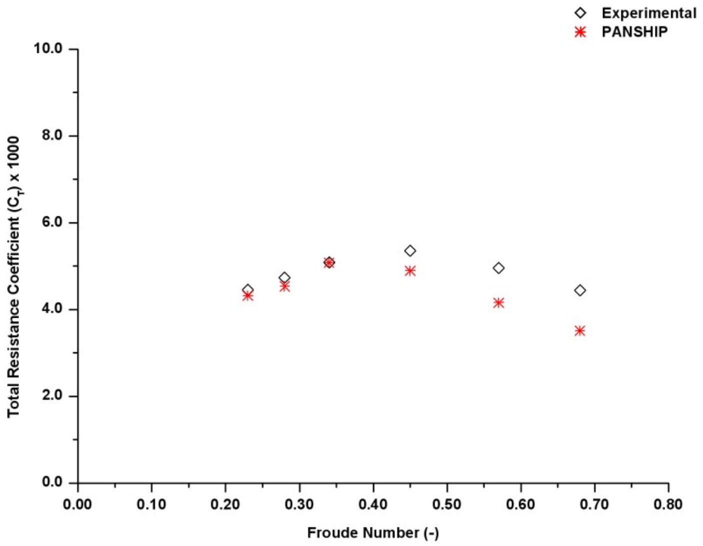

Figure 22 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (300.5 t displacement, 0.3 m static trim, trim tab in "neutral" position)

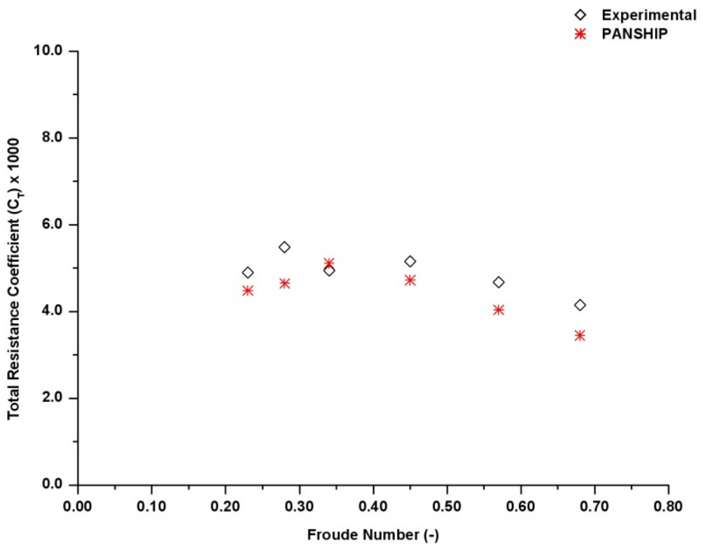

Figure 23 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (300.5 t displacement, 0.3 m static trim, trim tab in fully "extended" position)

Figure 24 shows three predictions using different numerical methods for the total resistance of the ACPB 300.5 t displacement 0.3 m static trim condition, trim tab "fully retracted", compared to the experimentally calculated total resistance. PANSHIP under predicts the resistance at the higher speed range by up to approximately 25 %. This trend is similar to that observed for the 300.5 t displacement 0.0 m static trim condition. This is consistent with the results that PANSHIP also slightly under predicts the rise of the vessel at these higher speeds. These differences may be attributed to slight differences between the numerical and the experimental model. This under prediction could also be attributed to PANSHIP neglecting the effect that spray drag has on the resistance and also the method by which PANSHIP approximates the ship generated wave. Both of these influences are subject to further investigation within the FAST3.JIP.

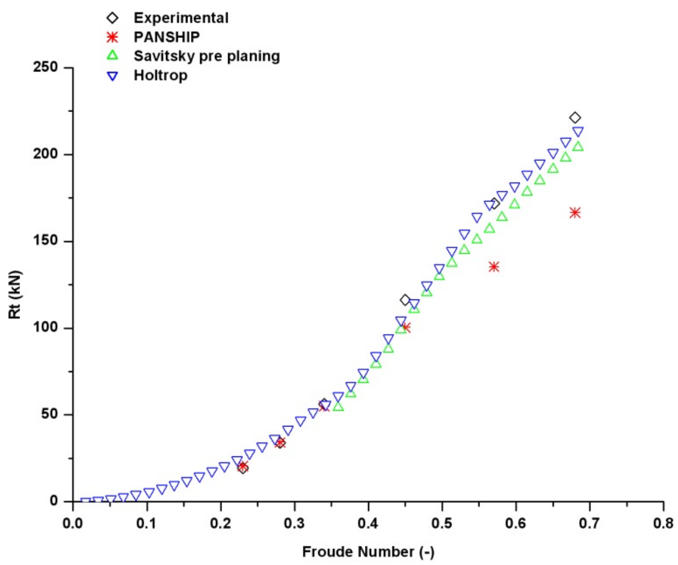

Figure 24 Experimentally determined and Numerically determined Total Resistance vs Froude Number (300.5 t displacement, 0.3 m static trim, trim tab in fully "retracted" position)

5.1.3 300.5 t displacement, 0.6 m static trim by the stern

Load Condition 3 was the same displacement as the previous two conditions but the static trim of the vessel was increased to 0.6m. Figure 25- 27 show the comparisons of the running trim angles vs speed for the three trim tab angles considered. Figures 28 - 30 shows the comparisons of the rise of the centre of gravity and Figures 31 - 33 shows the comparisons of the total resistance coefficient. Similar trends were observed for all these results as the previous two load conditions.

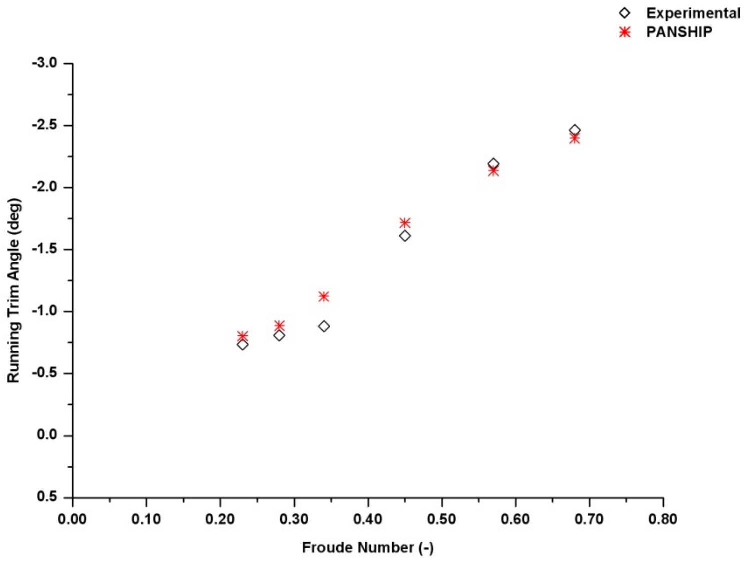

Figure 25 Experimentally determined and Numerically predicted Running Trim vs Froude Number (300.5 t displacement, 0.6 m static trim, trim tab in fully "retracted" position)

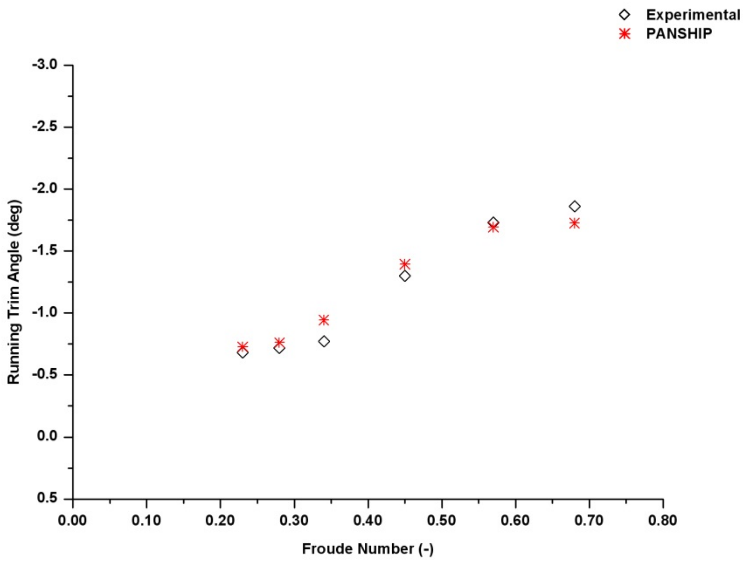

Figure 26 Experimentally determined and Numerically predicted Running Trim vs Froude Number (300.5 t displacement, 0.6 m static trim, trim tab in "neutral" position)

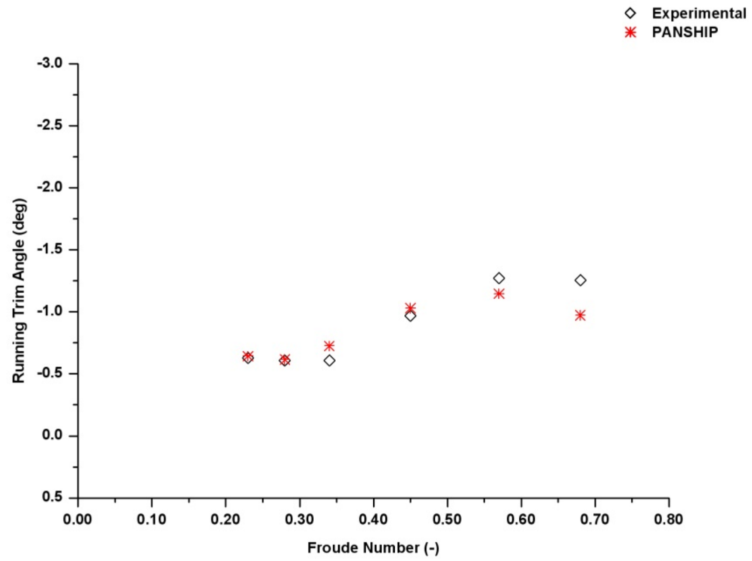

Figure 27 Experimentally determined and Numerically predicted Running Trim vs Froude Number (300.5 t displacement, 0.6 m static trim, trim tab in fully "extended" position)

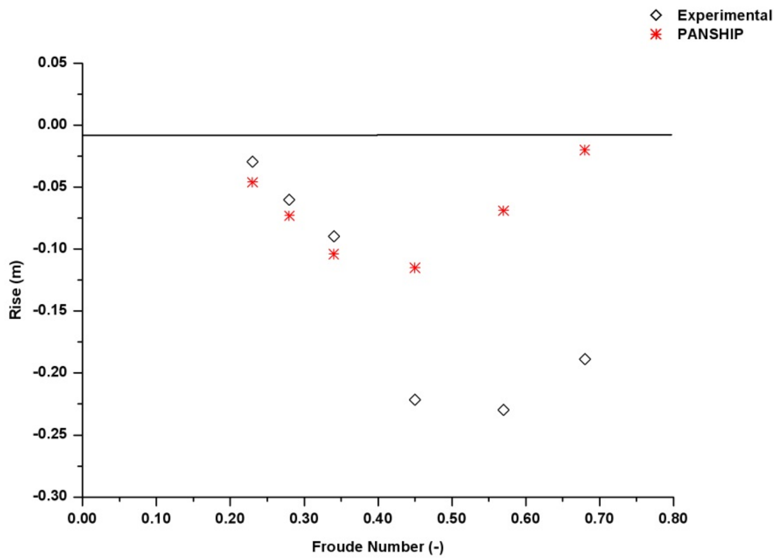

Figure 28 Experimentally determined and Numerically predicted Rise vs Froude Number (300.5 t displacement, 0.6 m static trim, trim tab in fully "retracted" position

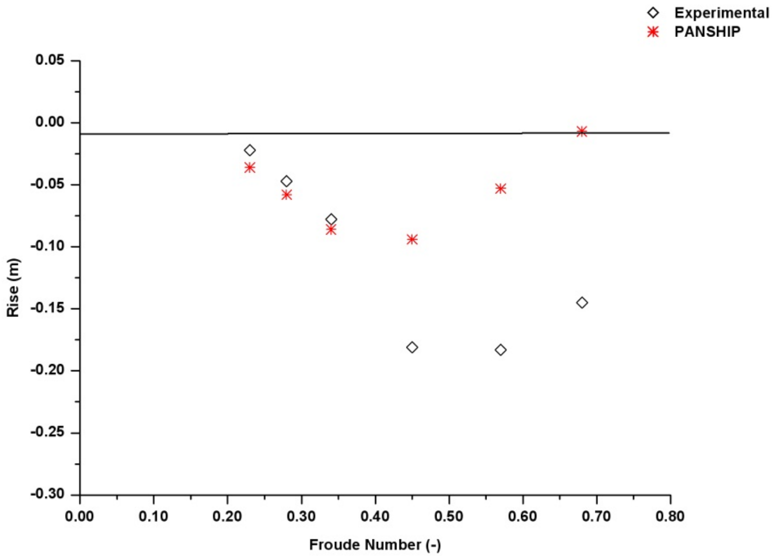

Figure 29 Experimentally determined and Numerically predicted Rise vs Froude Number (300.5 t displacement, 0.6 m static trim, trim tab in "neutral" position

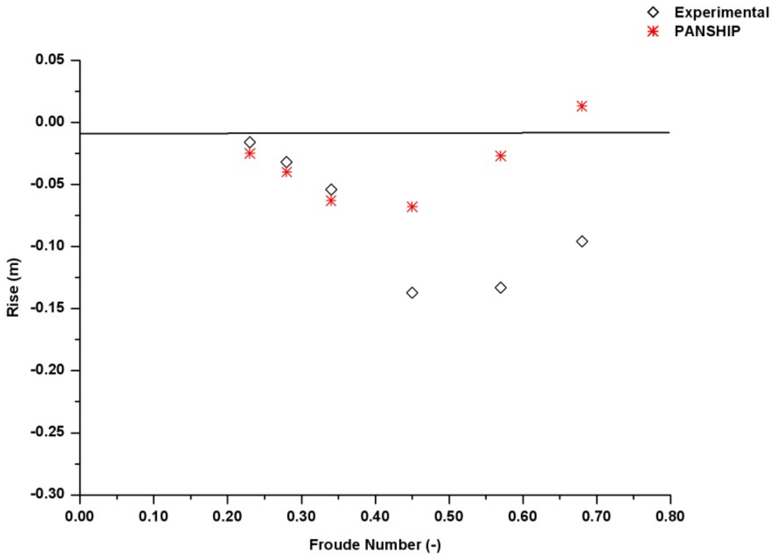

Figure 30 Experimentally determined and Numerically predicted Rise vs Froude Number (300.5 t displacement, 0.6 m static trim, trim tab in fully "extended" position

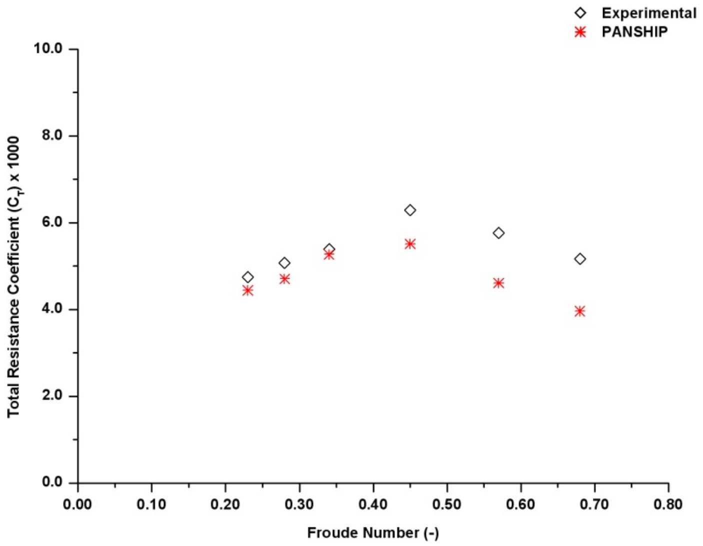

Figure 31 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (300.5 t displacement, 0.6 m static trim, trim tab in fully "retracted" position)

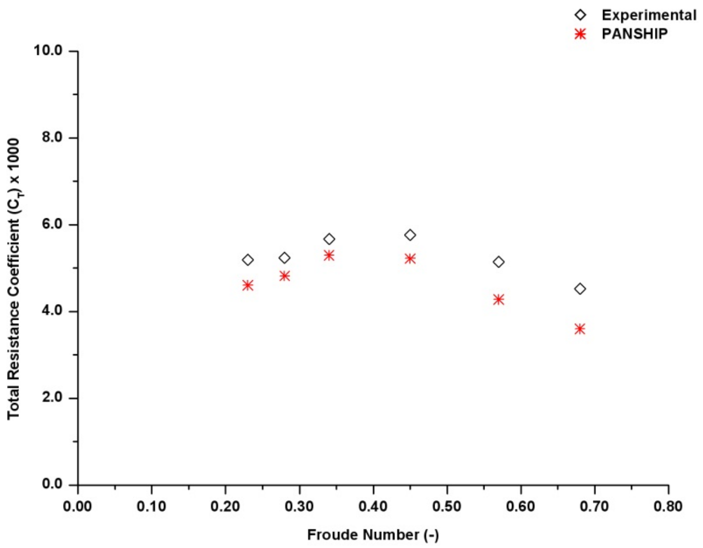

Figure 32 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (300.5 t displacement, 0.6 m static trim, trim tab in "neutral" position)

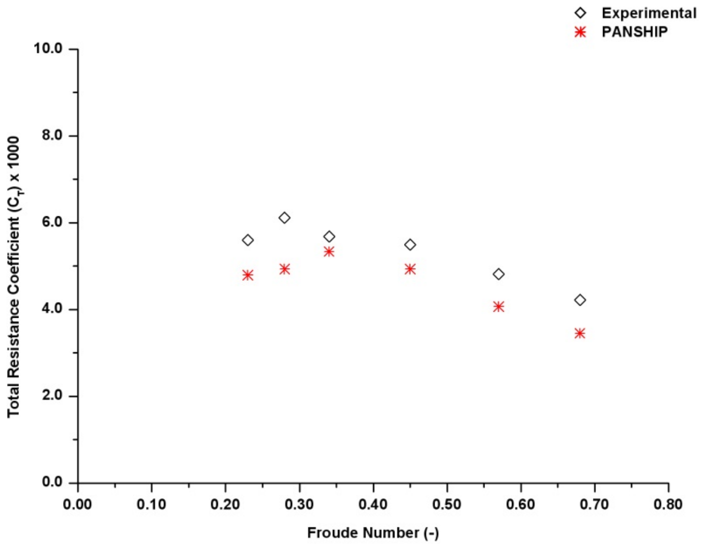

Figure 33 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (300.5 t displacement, 0.6 m static trim, trim tab in fully "extended" position)

Figure 34 shows the comparison between all three numerical methods for the prediction of the total resistance of the vessel. Once again the trend of the comparison between PANSHIP and the experimental results is an under prediction at high speeds.

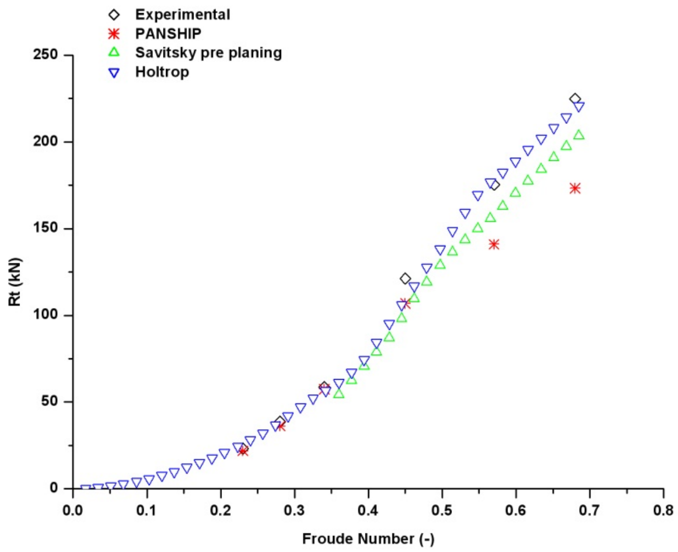

Figure 34 Experimentally determined and Numerically predicted Total Resistance vs Froude Number (300.5 t displacement, 0.6 m static trim, trim tab in fully "retracted" position

5.1.4 340.6 t displacement, 0.0 m static trim by the stern

The next load condition considered, Load Condition 4, was an increase in displacement to 340.6 t from the previous three load conditions with a 0.0 m static trim. The predictions of the running trim angles, rise and total resistance coefficient all showed very similar trends to those observed in the previous load conditions. Figures 35 - 43 show these comparisons.

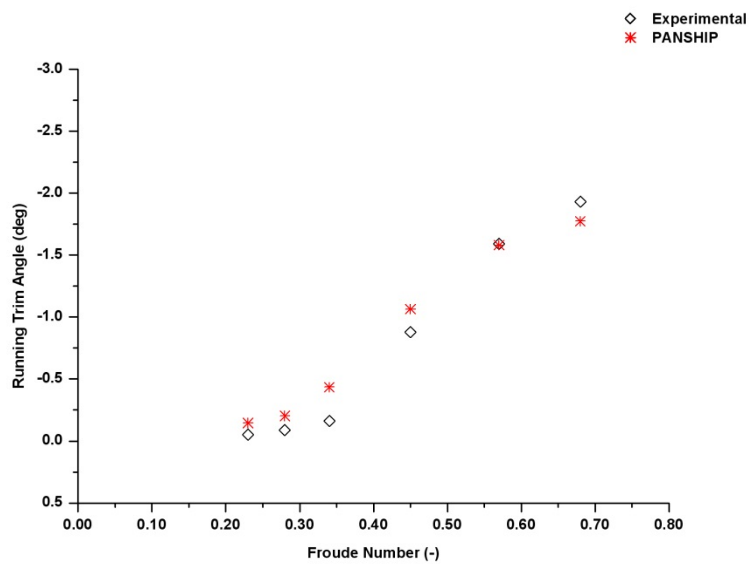

Figure 35 Experimentally determined and Numerically predicted Running Trim vs Froude Number (340.6 t displacement, 0.0 m static trim, trim tab in fully "retracted" position)

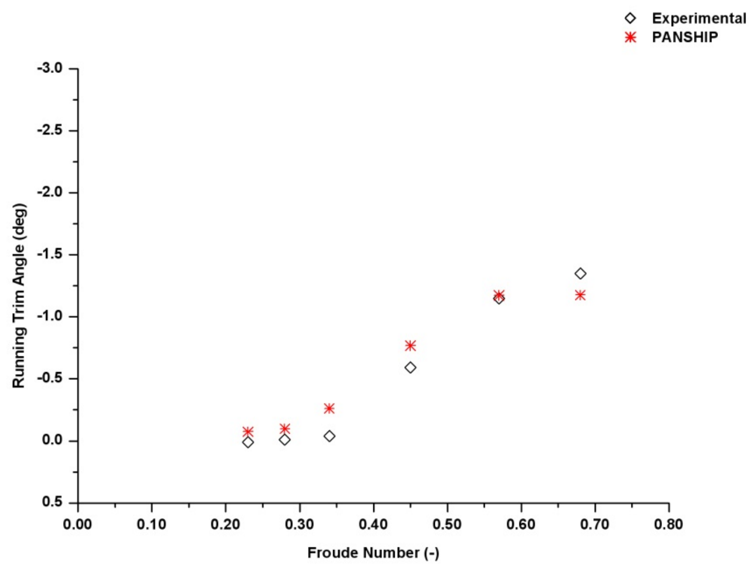

Figure 36 Experimentally determined and Numerically predicted Running Trim vs Froude Number (340.6 t displacement, 0.0 m static trim, trim tab in "neutral" position)

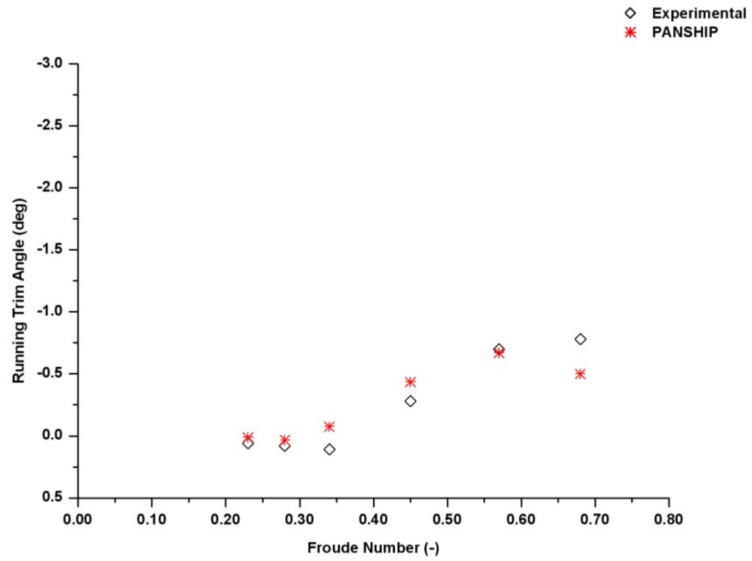

Figure 37 Experimentally determined and Numerically predicted Running Trim vs Froude Number (340.6 t displacement, 0.0 m static trim, trim tab in fully "extended" position)

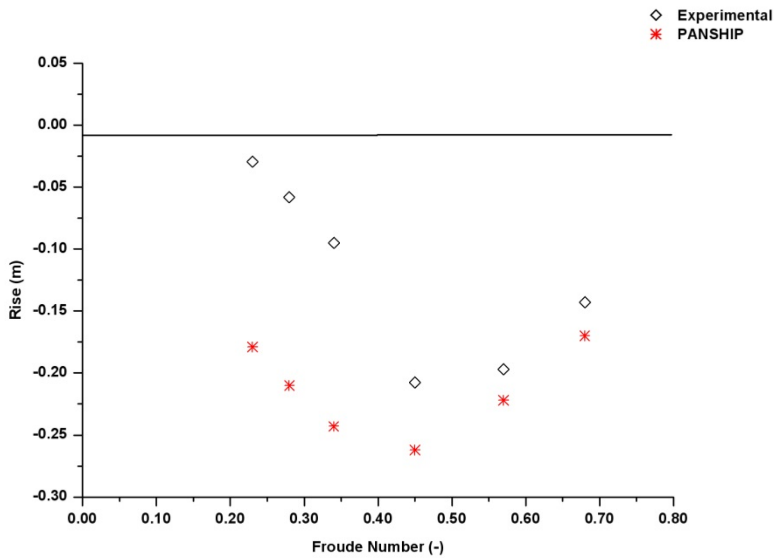

Figure 38 Experimentally determined and Numerically predicted Rise vs Froude Number (340.6 t displacement, 0.0 m static trim, trim tab in fully "retracted" position)

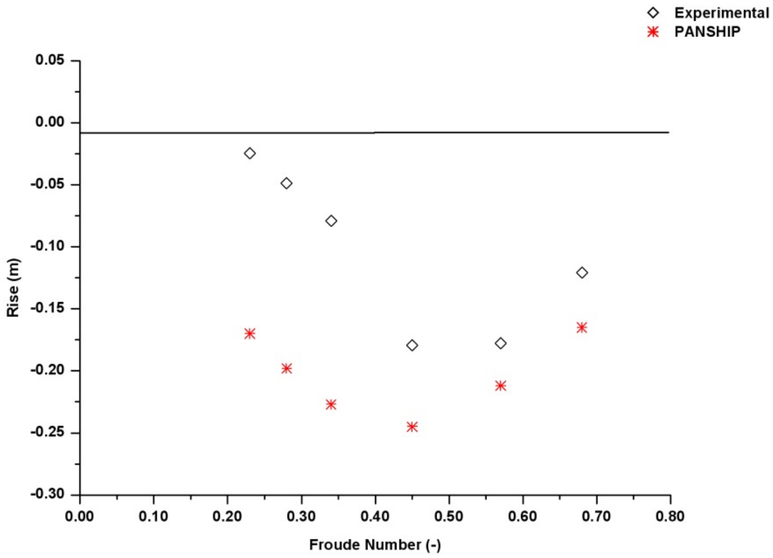

Figure 39 Experimentally determined and Numerically predicted Rise vs Froude Number (340.6 t displacement, 0.0 m static trim, trim tab in "neutral" position)

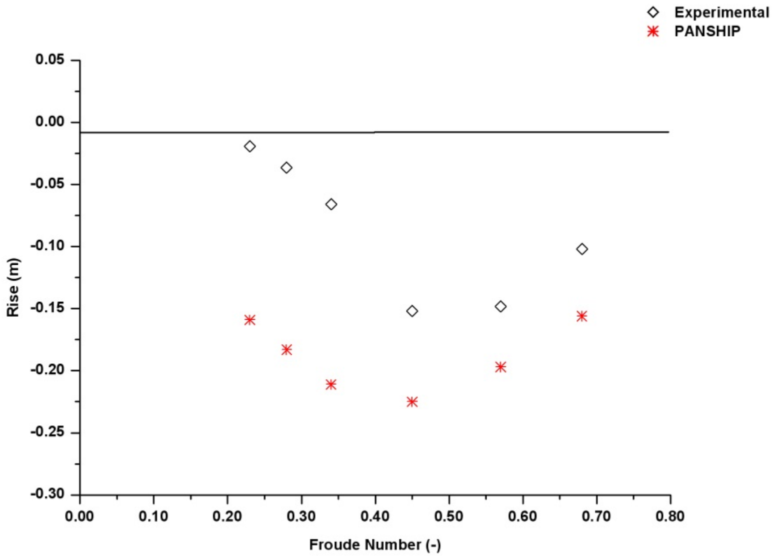

Figure 40 Experimentally determined and Numerically predicted Rise vs Froude Number (340.6 t displacement, 0.0 m static trim, trim tab in fully "extended" position)

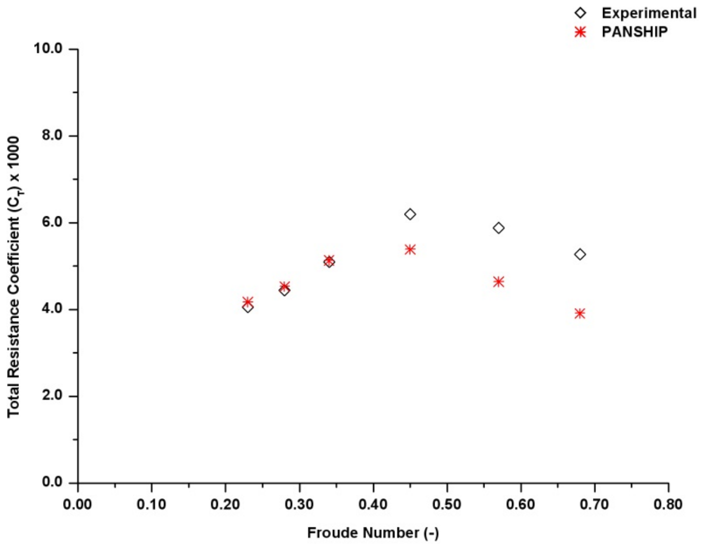

Figure 41 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (340.6 t displacement, 0.0 m static trim, trim tab in fully "retracted" position)

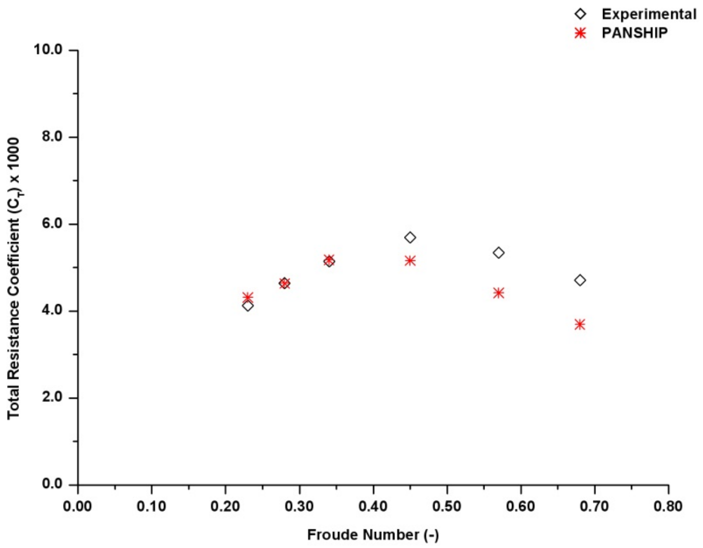

Figure 42 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (340.6 t displacement, 0.0 m static trim, trim tab in "neutral" position)

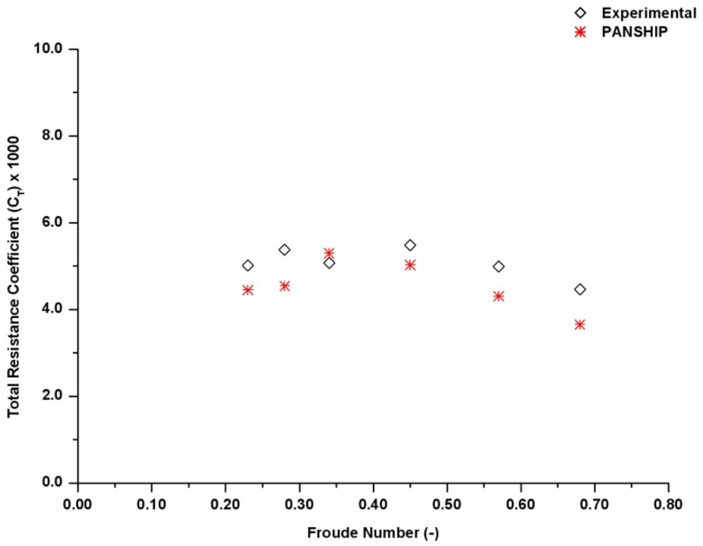

Figure 43 Experimentally determined and Numerically predicted Total Resistance Coefficient vs Froude Number (340.6 t displacement, 0.0 m static trim, trim tab in fully "extended" position)

Figure 44 shows the comparison between numerically determined and the experimental results for the total resistance vs speed for this load condition. Once again PANSHIP under predicts at high speeds.

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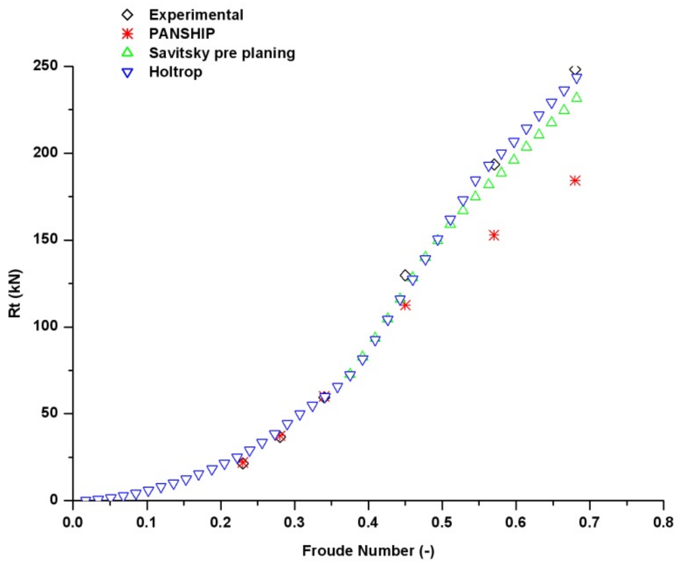

Figure 44 Experimentally determined and Numerically predicted Total Resistance vs Froude Number (340.6 t displacement, 0.0 m static trim, trim tab in fully "retracted" position)

5.2 Numerical Analysis of Full-scale Trials

The Defence Science and Technology Organisation has recently undertaken a powering sea trial onboard an Armidale Class Patrol Boat over a range of speeds. Figure 45 shows the comparison between the full-scale trial running trim versus speed and the PANSHIP predictions. A similar trend was observed to that seen in model test comparisons,(i.e. PANSHIP predicted the running trim of the ACPB to within 0.08 degree at the low and high speed ranges and overpredicted the running trim by 0.16 degree between Fn = 0.3 - 0.5).

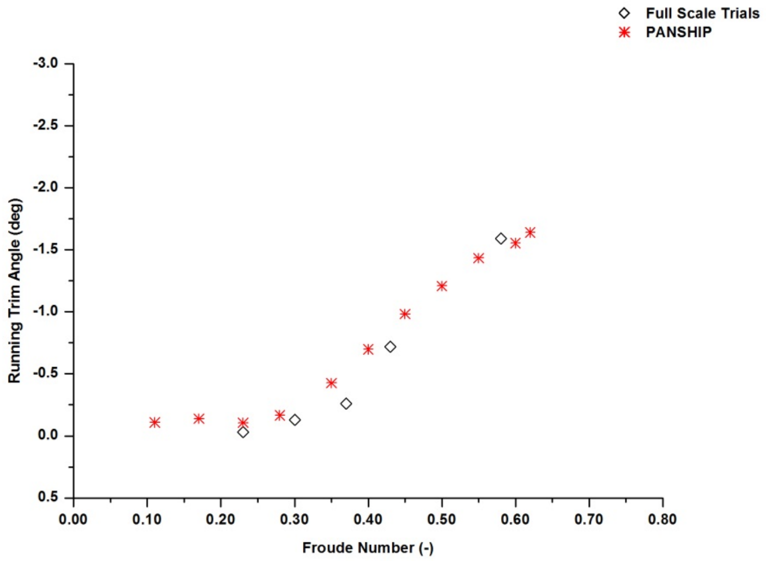

Figure 45 Sea Trial determined and Numerically predicted Running Trim vs Froude Number (300 t displacement, 0.0 m static trim, trim tab in fully "retracted" position)

PANSHIP and Maxsurf numerical predictions were also undertaken and compared with the total resistance of the ACPB calculated from the full-scale sea trial data. These predictions along with the comparisons are shown in Figure 46. PANSHIP slightly overpredicts, (up to approx. 9 kN), the full-scale trial results across the entire speed range considered. Note that the PANSHIP results have been factored up to consider the effect on the resistance due to skegs, fins, rudders and bilge keels. These correction factors were obtained from the MARIN DESP program based on similar vessel types. Potentially these correction factors were slightly too high. A correction factor for the effect wind on the resistance of the ACPB has also been considered in the PANSHIP results. The full-scale trials were also conducted during a slight wind. Depending upon the wind direction, this may also reduce the resistance of the ACPB determined from the trial.

At the lower speed range, the Savitsky pre planing predictions under predicted the resistance across the speed range considered whilst the Holtrop methodology under predicted the full-scale resistance at the mid speed range but as the speed increased this accuracy improved. As expected the scaled experimental results are lower than the full-scale trial. This is due to the experimental data not considering resistance due to appendages, wind and possible increase in hull roughness due to fouling. It should also be noted that the displacement of the ACPB for the full-scale trial was 10 t heavier than full-scale experimental displacement; hence a lower resistance would be expected for the experiments.

It is unclear as to why PANSHIP under predicts the model test experiments at the high speed range, see Figure 14 yet is reasonable for the full-scale trials. Potentially this is due to the additional resistance in PANSHIP due to appendages and the wind resistance for the trials compensating for this under prediction at model scale.

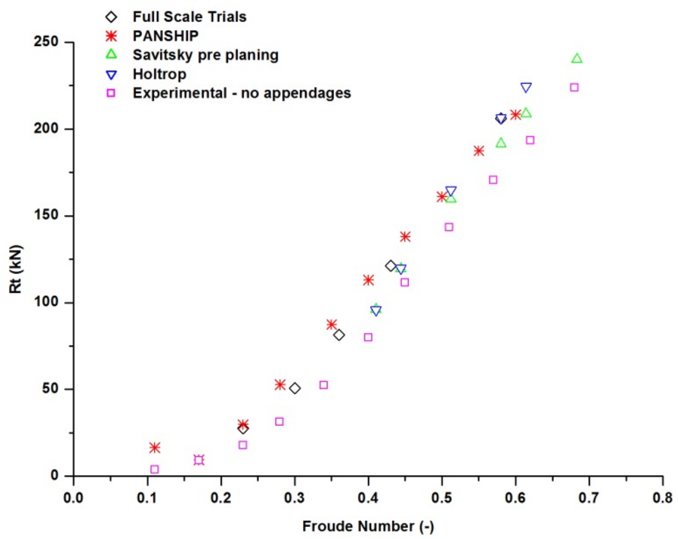

Figure 46 Sea Trial determined and Numerically predicted Total Resistance vs Froude Number (300 t displacement, 0.0 m static trim, trim tab in fully "retracted" position)

6. Conclusion

This report shows the outcomes of the validation studies of the numerical tool PANSHIP to model the calm water resistance, sinkage and change in trim of a semi-planing vessel, the Armidale Class Patrol Boat. Depending on the speed, the ACPB operates in displacement, semi-planing and planing modes. Traditional seakeeping, manoeuvring and resistance numerical prediction tools are based on the assumption that the hullform being considered is a displacement hullform. PANSHIP has the capability to model a vessel operating in displacement, semi planing and planing modes. These validation studies shown in this report compare PANSHIP predictions with experimental model test data, full-scale sea trials and other numerical prediction tools.

Outcomes from this study show that for all the load cases considered, PANSHIP predictions of the running trim compared very well with both experimental and full-scale sea trial data. When comparing the predicted total resistance of the ACPB to model test data, the resistance methodologies in the Maxsurf suite of tools were more accurate than

PANSHIP but the Maxsurf tools do not have the capability to model the effect that trim tabs have on the total resistance of the vessel. Although this capability exists in PANSHIP, preliminary validation studies have shown that the existing method may not be the best approach. Alternative methods for modelling the effect of the trim tabs are being investigated as part of the FAST3.JIP research program. When comparing full-scale sea trial data to the numerical predictions, PANSHIP proved to be the most accurate.

The development of the numerical simulation tool PANSHIP and the knowledge gained in this calm water resistance study will greatly enhance the understanding of the operational performance of the ACPBs. Outcomes will also provide guidance to the Royal Australian Navy for any potential cost saving strategies for fuel consumption.

PANSHIP has been validated for the sinkage and change in trim at various speeds for the ACPBs against experimental data. It was important to ensure that the calm water behaviour across the range of speeds is predicted correctly as this ensures the correct pressure distribution under the hull is predicted and hence the ship motions are accurate. This work will now be extended to validating the prediction of ship motions in waves and seaway loading, including slamming, experienced by the ACPB when operating in a variety of seaways. The accurate prediction of these loads is vital for the understanding of the structural strength and fatigue life of these vessels. PANSHIP has been developed to have the capability to predict these loads for vessels operating in both displacement and/or semi-planing modes. Experimental Model tests have been completed and full-scale sea trials are planned to record slamming pressure for validation purposes for this PANSHIP capability. Outcomes from this further work will be reported in future publications.

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19. ABSTRACT

DSTO has recently joined the International collaborative consortium FAST3.JIP with the aim to develop a numerical capability for the prediction and analysis of the resistance, seakeeping and seaway loads of high speed semi-planing hullforms. It has been reported previously that DSTO has undertaken a series of calm water resistance scaled model tests on the Armidale Class Patrol Boat (ACPB). In addition to this, DSTO has also undertaken a series of full-scale calm water resistance trials onboard an ACPB. Both the experimental data and full-scale powering trial data has been used to validate the numerical tool PANSHIP. It was important to ensure that the calm water behaviour across the range of speeds is predicted correctly as this ensures the correct pressure distribution under the hull is predicted and hence the ship motions are accurate. Once fully validated this tool can be utilised to increase the understanding of any potential fuel saving strategies for the ACPBs and the through-life structural management of the platform. This report presents the outcomes from this validation study showing the results of the PANSHIP predictions for experimentally obtained running trim, rise of centre of gravity and total resistance versus speed relationships and for running trim and total resistance versus speed relationships obtained from full-scale trials.